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With Two Plates.

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The absorption of ultra-violet radiations by various media has been the subject of numerous investigations which need not here be recounted. So far as modern optical glasses are concerned our knowledge rests chiefly on the researches of Krüss,[1] who investigated a series of ten typical Jena glasses by means of a fluorescent-screen polarizing photometer. His results extended to w. l. 309 $\mu\mu$ and included thicknesses of 1, 10, and 100 mm. of glasses ranging from a very light boro-silicate crown of index $n_D = 1.51$ to a dense silicate flint having $n_D = 1.67$. At the lower limit of wave length there was practically complete absorption by all these glasses in a thickness of 1 cm. and partial transmissibility for the lighter glasses in thicknesses of 1 mm. The most striking thing about his results was the generally similar form of the absorption curves and the very rapid increase of absorption below w. l. 350 $\mu\mu$ to 340 $\mu\mu$. For greater wave lengths than the first mentioned, optical glasses, save for the heaviest flints, are moderately transparent, as is found in ordinary practice. The writer, indeed, many years ago, photographed the solar spectrum down to Cornu's line O, w. l. 344 $\mu\mu$, through a large 45° prism of moderately dense flint, $n_D = 1.62$. Zschimmer[2] has added to Krüss' work an interesting investigation of the so-called Uviol glasses and some other optical glasses, with special reference to the value of the Uviol glass in transmitting the shorter wave lengths in the ultra-violet. His spectrograms show in some of the Uviol glasses transmission to as low as w. l. 265 $\mu\mu$ in a thickness of 2 mm., and down to about w. l. 295 $\mu\mu$ in a thickness of 10 mm. This shows, from the standpoint of transmissibility, a great improvement over the best of the ordinary glasses, spectra through which usually terminate at about w. l. 300 $\mu\mu$. Some extremely light crowns are a trifle more transparent.

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[1] Ztschr. f. Instrumentenkunde, **23**, 197, 229.

[2] Ibid., **23**, 360.

In the course of the investigation here undertaken, for example, the writer reached w. l. 289 $\mu\mu$ through 5 mm. of Parra-Mantois "crown extra léger," $n_D = 1.476$. The existence of glasses of this order of transparency is, as Zschimmer has pointed out, of importance in astrographic and spectrographic work in which it may be desirable to take advantage of all the rays which are transmitted by the atmosphere. As is well known, the atmospheric absorption becomes exceedingly strong below about w. l. 310 $\mu\mu$, and extinguishes the solar spectrum at about w. l. 295 $\mu\mu$. Below this point, absorption is complete for the whole thickness of the atmosphere, and as one nears w. l. 200 $\mu\mu$ it is practically complete, even for layers of a few cm. in thickness. This is the region in which the atmospheric absorption is displayed by very powerful ionization, which must therefore be a striking phenomenon in the upper regions of the atmosphere, since the solar light, composed as it is of well-known metallic radiations extending far into the ultra-violet, fails to show these only in virtue of atmospheric absorption.

The work of Krüss and of Zschimmer was carried on by means of spectrographs constructed of quartz, or quartz and fluorspar, and they both used, as a source, the quartz mercury lamp, which is by far the best available source for such investigations, inasmuch as when the lamp is held at a uniform current it gives a wonderfully steady radiation, which is not true of any other source rich in ultra-violet rays.

From another standpoint, that of the investigation of glasses particularly adapted to cut off the ultra-violet, which are of interest to the student of physiological optics, several investigators have recently attacked the problem. In particular, important researches have been published by Voege,[3] Hallauer,[4] and Schanz and Stockhausen.[5] The studies from the ophthalmological side have unfortunately mostly been made with open electric arcs of various kinds, which are subject to so considerable fluctuations, even under the most favorable circumstances, as to make the comparison of different spectrograms, even when taken in immediate succession, somewhat untrustworthy, although the distribution of intensity in a single spectrogram may be judged with considerable confidence.

In fact the quantitative value of spectrographic studies is somewhat limited, even with the steadiest sources of radiation, on account of the different performance of different makes of photographic plates and the varying action of developing and fixing baths. One can, however,

[3] The Illuminating Engineer, London, **2**, 205, 543.
[4] Archiv. of Ophthalmology, **21**, 1.
[5] Ztschr. f. Augenheilkunde, **23**, 397.

by uniform methods of treatment, get results which have a comparative value great enough to decide most of the important questions which come up for consideration in studying ultra-violet absorptions.

Having a quartz lamp and spectrograph set up for another research, it seemed desirable to the writer to take advantage of this apparatus for the preliminary investigation of some of the glasses commonly used in the practice of American opticians, since the data already referred to apply chiefly to glasses exploited mainly upon the Continent. The apparatus used was the concave-grating spectrograph of the Rogers Laboratory of Physics, kindly placed at the writer's disposal by the Director. It is fitted with a Rowland concave grating of approximately 1.75 meters radius of curvature, mounted in the ordinary Rowland manner. The grating itself has a ruled surface 24 × 50 mm. ruled with about 14,438 lines per inch. The plateholder takes plates up to 3 × 13 cm., and the whole instrument is set up in a light-tight room with the slit and the source outside. The lamp employed was one of the ordinary quartz mercury lamps of the French Cooper-Hewitt Co., operating at about 200 volts. In these investigations it was used at a normal current of 4 amperes. The lamp was set up about 90 cm. from the slit, and the tube was focussed upon it by a quartz lens of about 20 cm. focal length. An ammeter was kept in circuit with the lamp so that the current could be adjusted to a uniform value by a rheostat. The path of the rays from lamp to plateholder was thus slightly less than 4.5 meters. Inasmuch as only the violet and ultra-violet portion of the spectrum was thus investigated, ordinary photographic plates (Seed's No. 27) were used. These were developed, each set of exposures together, in a large tray, with 5 per cent rodinal for 5 minutes, and fixed together in stock hypo-solution. Except for special purposes of comparison in which other exposures are stated, the plates were exposed for a uniform period of 5 minutes and developed as soon as each particular set had been exposed, the spectrograph room being fitted with facilities for doing this. The printing was likewise done in groups to secure uniformity.

The glasses investigated included a few optical glasses which seemed to be of interest, and a group of colored glasses of the kinds frequently used for protective spectacles in this country. In working close to the quartz lamp, which was so situated that one had to work at times within half a meter, the operator's eyes were protected by spectacles composed of two of the glasses referred to later, but such protection seems to be quite unnecessary in ordinary working around the laboratory with this lamp. In fact the writer was convinced, during a long period of experimenting, that the dangers to the eye from the quartz

lamp, although not negligible under extreme conditions, have been very much exaggerated. These observations in fact quite confirm the recent statements of Birch-Hirschfeld [6] on this subject. The ordinary care which one exercises in keeping intensely brilliant lights out of the eye at short range seems also sufficient to avert any trouble from the specific effects of extreme ultra-violet radiations.

The accompanying plates, all taken with a rather wide slit, about .2 mm., summarize the results obtained.

Figure 1, Plate 1, shows the ultra-violet spectrum of the quartz lamp from about w. l. 410 $\mu\mu$ to about w. l. 310 $\mu\mu$, as shown by the approximate wave-length scale above. It will be noted that, save for the brilliant triplet near w. l. 365 $\mu\mu$, the region of the ultra-violet, down to the double at about w. l. 313, has very few strong lines, and the region between the two groups mentioned is especially barren. There is in fact much less total strength apparent in the part of the quartz-lamp spectrum shown on these plates, than appears in the spectra of the sun and of ordinary electric arcs, the strong mercury lines being few. It is only in the extreme ultra-violet beyond the range shown in Plate 1, that the mercury spectrum is particularly brilliant.

Figure 2, Plate 1, shows the same spectrum when cut down by a polished plate of A.O. crown glass 6.2 mm. thick. The weakening of the further ultra-violet is here very marked, especially in case of the doublet at w. l. 313 $\mu\mu$. The absorption near the other end of the strip is comparatively small and, in fact, the glass may be said to be moderately transparent to near w. l. 313 $\mu\mu$. No lines of the mercury spectrum of less w. l. than this appear on this plate or on any other of the plates reproduced herewith. In other words, all the glasses tested and shown in these spectrograms cut off completely all radiation of w. l. less than that stated. The A.O. crown is one of the glasses commonly used for spectacle lenses in American practice.

Figure 3, Plate 1, is the quartz arc spectrum as reduced by a medium tint of ordinary commercial "smoke" glass 5.6 mm. thick. In this case everything of less w. l. than about 360 $\mu\mu$ is completely obliterated. The strong group near w. l. 365 $\mu\mu$ gets through with a fair degree of brilliancy, and a similar moderate absorption extends into the violet and elsewhere into the visible spectrum.

Figure 4, Plate 1, is the spectrum as reduced by a plate of B. & L. crown 4.2 mm. thick, a glass also much used for spectacles and comparable with Figure 2. It has, however, a slightly higher refractive index and shows more absorption in the extreme lines and not quite as

[6] XI Congresso Internazionale di Oftalmologia, p. 623.

much, owing perhaps to its less thickness, in the left-hand side of the spectrum. It is, however, moderately transparent to the ultra-violet.

Figure 5, Plate 1, is the result obtained from a very pale amethyst glass in a thickness of 2.8 mm. This is a glass which has been considerably used for protective spectacles in which great density may not be desirable. It absorbs a trifle more of the extreme rays than do the clear crown glasses, and conspicuously more from the violet to and below w. l. 360 $\mu\mu$. The appearance of the spectrogram suggests somewhat selective absorption, but it is little more effective as regards absorption in the ultra-violet generally than the common smoke glass.

Figure 6, Plate 1, is a protective glass of a curious light yellowish-pink hue, which has been considerably used under the name of Arundel tint. It shows considerably stronger absorption than the amethyst glass, especially for the shorter rays; the doublet at w. l. 313 $\mu\mu$ is completely wiped out. The next conspicuous line at w. l. 334 $\mu\mu$ is very greatly reduced in intensity, as is indeed the remainder of the ultra-violet shown in this spectrogram. It also reduces the blue end of the visible spectrum slightly, although its general tint is very light.

Figure 7, Plate 1, is the quartz arc spectrum of Figure 1 as reduced by a slip of Fieuzal glass 4 mm. thick. It completely obliterates the whole ultra-violet region and the blank spectrogram is introduced here merely for sake of contrast. It is a medium tint of yellowish-green glass, cutting out much of the violet and blue and reducing considerably the blue-green, although, since it retains all the rays of highest luminosity in the spectrum, it does not cut down the total light sufficiently to serve as a protection against arc lamps or other extremely brilliant lights. It is, however, a pleasant and effective glass where considerable reduction in intensity is not required.

Figure 8, Plate 1, also a complete blank, was produced by a sheet of ordinary commercial amber glass of medium tint and 2 mm. thick. Its absorption of the ultra-violet is complete, and is strong in the violet, blue, and blue-green. Its tint is due to letting through the red a little more freely than does the Fieuzal glass just considered, which in general properties it resembles rather closely. It is not sufficiently dense to protect adequately against the dazzling effect of very brilliant sources of light in the tint here examined, but is dense enough to serve all ordinary purposes well. Its extinguishment of the ultra-violet, however, is most complete, a property which it probably shares with many other varieties of yellowish and orange-tinted glasses. A slip of a reddish amber selenium glass, such as is sometimes used for railway signals, 3.5 mm. thick, likewise cut off the whole ultra-violet region, giving a blank spectrogram. This last-mentioned glass absorbed power-

fully, clear down into the green, and, while fairly transparent to the rays of high luminosity, was preferable to either of the glasses just described for reducing the painful glare of powerful illuminants.

Figure 9, Plate 1, taken at the end of this series, shows again the spectrum of the bare quartz tube with an exposure of 15 seconds. The plate therefore, in this case, received just five per cent of the total energy recorded on Figure 1, Plate 1. The line near w. l. 391 $\mu\mu$ appears faintly in the negative, but is lost in the reproduction. The line near w. l. 405 $\mu\mu$ does not appear on this plate since, in this case, as in some of the others, the plateholder had been shifted by a small amount in order to reach down a little further into the ultra-violet. A comparison of this plate with those showing the effects of the absorbing glasses gives a vivid idea of the extent of the absorption produced by the glasses, especially those having even slight coloration.

In connection with these figures of Plate 1 should be considered Figure 8 of Plate 2, exposed under parallel conditions for 15 minutes. This shows the extreme ultra-violet portion of the quartz lamp spectrum, the last line visible in the reproduction being at w. l. 230 $\mu\mu$. With the exception of the doublet at w. l. 313 $\mu\mu$, this portion of the ultra-violet was obliterated by the absorption of the glass in all the spectrograms shown. The relatively great richness of the spectrum in the extreme ultra-violet portion down to about w. l. 230 $\mu\mu$, where atmospheric absorption became very powerful, is conspicuous in this figure. In the lower portion of this spectrum are indicated the so-called "abiotic" radiations, which are particularly active in cell destruction, and as the quartz lamp here tested was put to use for bactericidal experiments, this portion of the ultra-violet was of special interest. As Cernovodeanu and Henri [7] have shown, the bactericidal effects are practically confined to wave lengths below 270, and increase beyond this point with enormous rapidity, an effect very possibly corresponding to the powerful ionization produced in this part of the extreme ultra-violet.

Figures 1 to 7, inclusive, of Plate 2, are not strictly comparable with the figures of Plate 1, since they were taken at a later period, after the spectrograph had been in use for other work. The apparatus was set up anew. The grating was turned over, giving a somewhat more brilliant first order spectrum, and the brightest portion of the quartz tube was focussed upon the slit. The exposure in this series was, except when noted, 5 minutes, as before, but the intensities were notably higher.

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[7] Elektrotechnik u. Maschinenbau, **28**, 69.

Figure 1 shows the spectrum of the bare tube under these new conditions at the same current of 4 amperes used in all the spectrograms, and needs no further comment.

Figure 2, Plate 2, is an interesting illustration of the powerful absorption produced by a modern anastigmat lens in the ultra-violet portion of the spectrum. It was obtained merely by substituting the photographic lens for the quartz lens previously used in focussing the tube upon the slit. The particular lens used was a Zeiss Unar, series 1 B No. 5, of 155 mm. equivalent focus. This lens is composed of 4 thin separate elements, having an aggregate mean thickness of between 10 and 11 mm. It will be noted that the absorption for wave lengths less than 365 $\mu\mu$ is very active, and that all the ultra-violet lines are somewhat weakened. The practical significance of the spectrogram is that even the first-class modern photographic lens is practically almost opaque to wave lengths below 365 $\mu\mu$, and it points out the necessity of using special glasses and special constructions for spectrographic or astrographic work. For there is ample intensity in the ultra-violet spectrum of daylight to give trouble were the lens fully transparent down to the limit of the rays ordinarily transmitted by the atmosphere. As Zschimmer has shown,[8] one can work clear down to this limit with the Uviol glasses, which of course should be achromatized with this point in view. The Unar lens, like some others of recent type with separate lenses, suffers more from loss of light by reflections at the multiple surfaces than would the older anastigmats with thick cemented lenses, but probably much more than makes up for this loss by the lessened thickness of glass. The loss from reflections is quite a serious matter, inasmuch as the refractive index of an ordinary crown at say w. l. 350 $\mu\mu$ to 340 $\mu\mu$ is in the vicinity of 1.55 and that of ordinary flints is about 1.65. Reckoning the losses by Fresnel's formula, $\left(\frac{n-1}{n+1}\right)^2$, without applying additive corrections for the obliquity of incidence, it appears that in a 4-lens separated system the loss of light by reflections will amount to nearly 35 per cent in this region of the spectrum; and assuming a thickness of 10 mm. for the crowns and an equal amount for the flints, the absorptive loss for the former can scarcely be less than 20 per cent and that in the latter scarcely less than 70 per cent, so that on the whole hardly 20 per cent of the incident light would reach the plate. Evidently the increased absorption due to the greater thickness of glass would more than overbalance the gain from reduced reflections in the case of anastigmat lenses of the common symmetrical cemented type in

[8] Loc. cit.

which the total thickness would be at least doubled for the same aperture.

Figure 3, Plate 2, shows the absorption of a slip of clear green signal glass, 2.4 mm. thick. This particular glass gives absorption in the violet and in the red and orange, and transmits not over 15 per cent of the total light. The absorption in the further ultra-violet is complete, and even the group at w. l. 365 $\mu\mu$ gets through enormously weakened. The particular protective spectacles previously mentioned were made of a layer of this glass and of the reddish amber selenium glass before mentioned, of equal thickness. They completely suppressed the ultra-violet, violet, blue, much of the green and also most of the red and orange, leaving a nearly monochromatic strip in the most luminous part of the spectrum. The resulting combination transmitted ample light to enable one to read instruments and notes, or even to read a newspaper in fairly strong light, but cut down the intensity to a point that enabled one to look with comfort at short range into the quartz lamp or the most powerful commercial flaming arcs.

Figure 4, Plate 2, is the same amber glass as Figure 8, Plate 1, taken with the stronger illumination. Two of the lines in the violet came faintly through, but the ultra-violet was completely suppressed.

Figure 5, Plate 2, is the same glass as in Figure 7, Plate 1. This as before completely suppressed the ultra-violet and let through the two violet lines very faintly.

Figure 6, Plate 2, is the spectrum taken through a slip of No. 1 Euphos glass, 4 mm. thick. This is a light yellowish green in color, suppressing the blue and violet somewhat less completely than the two previous glasses, but like them blocking out the ultra-violet effectively. None of the four glasses just described cuts down the intense light of the quartz lamp or arc lamps, when viewed at short range, sufficiently to avert ocular distress after a short exposure. For adequate protection against such sources considerably deeper shades of all of them are necessary and are readily available. It must be borne in mind in this connection that among arc lamp workers and operators of electric furnaces cases of the so-called *ophthalmia electrica*, which is chargeable to the extreme ultra-violet rays, chiefly the abiotic radiations already referred to, are rare compared with distressing symptoms due to the luminous rays. Protective glasses, therefore, as light in tint as these of Plate 2 are, as a matter of practical experience, of comparatively little service although they suppress the ultra-violet quite completely. Deeper shades of any of them may be effective.

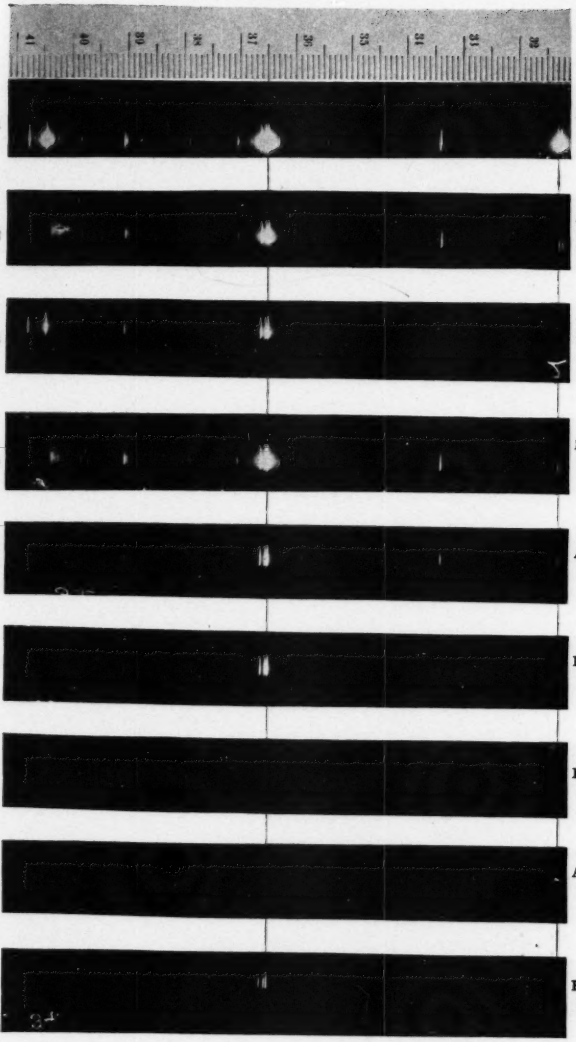
Figure 7, Plate 2, is an exposure of the bare quartz tube for 5 seconds. This spectrogram received therefore 1.66 per cent of the

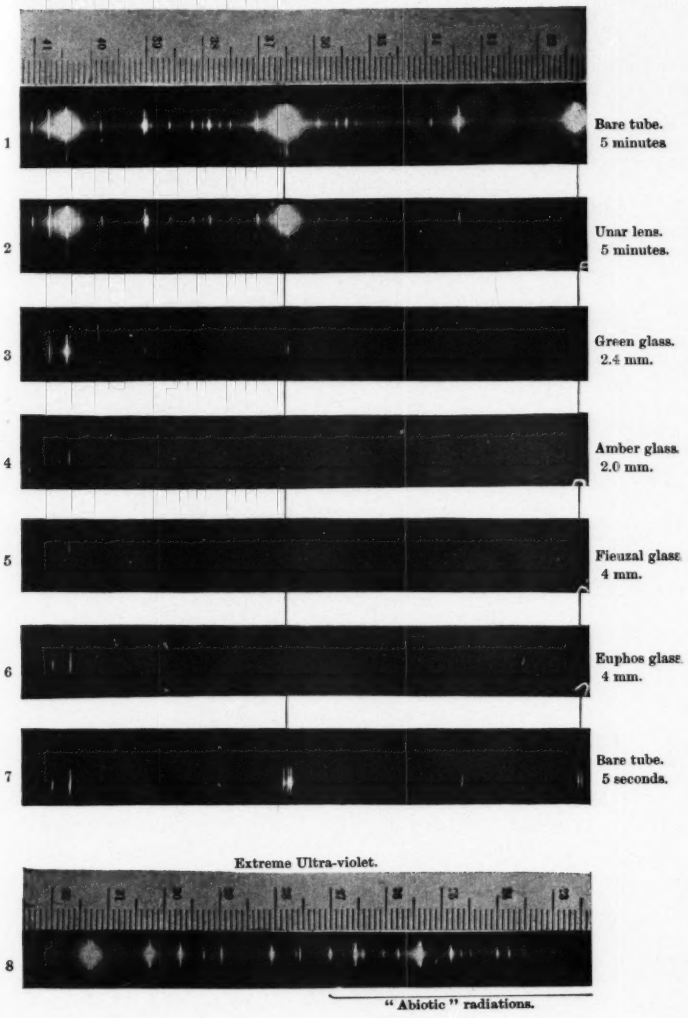
total energy received by Figure 1, Plate **2**, and well exhibits the effectiveness of the absorption produced by the glasses considered in the whole ultra-violet region. Without going here into the matter of any specific effects due to the action of the ultra-violet rays upon the eye it is interesting to compare the results here obtained with those derived from some of the other protective glasses recently brought to notice. From the very interesting studies of Hallauer[9] it appears that the so-called enixanthos glass shows absorption very similar to that of the Fieuzal, while Hallauer's own glass possesses similar characteristics in the ultra-violet, but like the amber glass here described carries a stronger absorption into the blue. The Gonin rose glass apparently resembles the pinkish glass of Figure 6, Plate **1**, while the blue glass is still more transparent to the shorter wave lengths. Hallauer's gray glass apparently corresponds quite closely to the smoke of Figure 3, Plate **1**. The commercial red glass tested by Voege[10] cut off the ultra-violet completely in a thickness of 2.9 mm. Broadly the red, amber, yellowish and yellowish-green glasses which absorb noticeably in the blue and violet also carry increased absorption through the ultra-violet, while the blue and green glasses which transmit somewhat freely in the blue and violet also transmit a perceptible amount of ultra-violet. This latter class of glasses is undesirable for protective use for other reasons than those connected with the ultra-violet, however, since a predominant blue tone in the transmitted light is both of uncomfortably low luminosity and greatly reduces the contrasts in most objects viewed. Of the amber and greenish glasses all will transmit, when of light tint or very thin, a limited amount of the more refrangible rays, including some ultra-violet, as would readily be found by a very prolonged exposure. The ultra-violet radiations transmitted by any of them when of sufficient thickness or density to be of service in softening the intensity of the visible rays is extremely trivial in amount, so small as to be utterly negligible in practice, as the spectrograms given show, and all of them, even the lightest in tint, suppress very thoroughly the only radiations in the ultra-violet that are certainly known to have a specific harmful effect. To sum up this matter of protection against the ultra-violet: All ordinary glasses, even the clear optical glasses, suppress all the ultra-violet radiations certainly known to have a specific harmful effect upon the human eye. As to the rest of the ultra-violet, say from w. l. 300 $\mu\mu$ to the visible rays, there is little clinical evidence of injurious effect, and even this little does not gain in convincing quality from its

[9] Loc. cit.

[10] Loc. cit.

too frequent association with perfervid commendation of somebody's special variety of protective glass. If as a matter of precaution it be thought desirable in certain cases to cut off the whole ultra-violet region, there is a liberal choice of entirely effective glasses available. For this purpose the common commercial amber glasses such as are used for spectacles and signal lenses seem to be quite as effective as those especially made for such use, the choice between them being chiefly a matter of taste. The very lightest tints of all of them undoubtedly may transmit faint traces of the ultra-violet rays nearest the visible spectrum, but when there is density enough materially to soften the visible light these traces disappear. For protection against powerful sources of light at short range only the deepest tints reduce the visible light sufficiently, and these are particularly opaque to the ultra-violet.


1
Bare tube.
5 minutes.
2
A.O. Crown.
6.2 mm.
3
Medium smoke.
5.6 mm.
4
B. and L. Crown.
4.2 mm.
5
Amethyst glass.
2.8 mm.
6
Pinkish glass.
4.6 mm.
7
Fieuzal glass.
4.0 mm.
8
Amber glass.
2.0 mm.
9
Bare tube.
15 seconds.


1
Bare tube.
5 minutes.
2
Uvar lens.
5 minutes.
3
Green glass.
2.4 mm.
4
Amber glass.
2.0 mm.
5
Fieuzal glass.
4 mm.
6
Euphos glass.
4 mm.
7
Bare tube.
5 seconds.
Extreme Ultra-violet.
8
"Abiotic" radiations.